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Premixed Atmosphere and Convection Influences on Flame Inhibition and Combustion (PACIFIC)

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Objective

Under NASA-Lewis Grant NAG3-1611, starting date 6/1/94, a three-year experimental and theoretical study of the effects of ambient atmosphere on the properties of flame spread over thin and thick solid fuel beds has been initiated. In particular the effect of the type of inert gas, which affects the Lewis numbers of fuel and oxidant, and the effect of the addition of sub-flammability-limit concentrations of gaseous fuels to the oxidizing atmosphere will be studied. The effect of convection will be studied through one-g and µg experiments with and without a forced flow. Moreover, the influence of thermal radiation, whose effect is known to be markedly different depending on the convection level, will be addressed.

Approach

The emphasis of this study is on thermally thin fuels because of the limited µg test time available in ground-based facilities, but preliminary scaling analyses suggest that it may be possible to study thermally thick fuels as well when gaseous fuel is added to the oxidizing atmosphere.

The experiments will be conducted in a combustion chamber in which a convective flow of a few cm/sec can be imposed in the direction opposite the flame spread. The oxidizing atmosphere will be mixed by the partial pressure method. For tests of Lewis number effects, the inert gases He, Ne, N_2, CO_2 and SF_6 will be used since they provide Lewis numbers from about 0.3 to 1.4. CO and CH_4 will be used for the gaseous fuels. Thin fuel samples will be ashless filter paper and thick fuel samples will be PMMA. Fuel samples of varying thickness will be ignited by the heat generated by a current passed through a coiled nichrome wire coated with nitrocellulose.

The primary diagnostics are video and an array of fine-wire thermocouples to measure the temperature simultaneously at several locations. The video records provide information on the spread rate and flame shape. The thermocouples give an independent check of the spread rates and the existence (or lack thereof) of a separate flame front in the case of added gaseous fuel. The temperature data may also be used to determine the heat flux from the gas phase to the fuel bed, which can be related to the spread rate.

Significance

The understanding and control of accidental fires is a critical safety issue in both terrestrial and space-borne environments. The proposed work would provide insight that could be used to assess the fire hazards associated with non-standard atmospheres that might be employed in future manned spacecraft. Also, fires in enclosures produce a considerable amount of unburned vaporized fuel and partially combusted gases such as CO. One-g experiments have shown that the addition of combustible gases such as CO to the oxidizing atmosphere may increase the flame spread rate substantially. This study could provide information to improve models of fire development and spread in enclosures at one-g and μg.

The influence of weak forced convection is particularly important for studies of flame spread at μg because there is very little buoyancy-induced flow at μg. Experiments by Olson and collaborators shows that the presence of forced convection currents (for example due to ventilation systems in manned spacecraft) can have a profound effect on the spread rate and extinction conditions. Consequently, the understanding of these effects is critical to understanding how fires might start, spread, and be extinguished at μg conditions.

Progress

To improve the sensitivity of the video imaging system for the very weak near-extinction flames, a shearing interferometer (Fig. 1) has been designed and is being constructed for evaluation. The shearing interferometer has no parts that have critical alignment requirements, and thus may be especially suitable for drop tests. The interferometric measurements may also be useful to supplement the thermocouple temperature measurements. A system has been constructed and bench-tested and has been found to provide excellent resolution and sensitivity for flame spread experiments (Fig. 2). Both finite fringe spacing and infinite fringe spacing configurations have been tested. The infinite fringe spacing configuration has been selected for the drop apparatus because it appears to be easier to quantify the recorded images from the infinite fringe system to obtain temperature information. The system is sensitive enough to detect temperature differences of only a few degrees Kelvin in air, though sensitivity of this level is not required to image flames. This system is now being integrated into our drop-tower flame spread experiment. All optical components and cameras have been obtained, and the mounting system is being fabricated.

A graduate student has built a new test chamber and flame spread apparatus to supplement the PI's existing apparatus. The test combustion chamber is based on Lewis's now-standard layout for 2.2 second drop tower experiments. The new chamber and apparatus provides improved fuel sample mounting, optical access for direct photography and interferometry, a rapid ignition system and an updated

Tattletale-based data acquisition system. This equipment is now being integrated into a standard 2.2 Second drop tower frame. Preliminary one-g tests have been conducted to verify previous results in the PI's laboratory and elsewhere. Initial μg experiments are planned for the summer of 1995.

The PI's existing computer-controlled partial pressure gas mixing system has reconfigured for the planned experiments. An undergraduate student has re-written the partial pressure gas mixing software using a nonlinear least-square fit algorithm to obtain successively improved estimates of the final pressure after gas is added to the chamber, to minimize the total time required to mix the gases and maximize the accuracy of the final mixture. This gas mixing system is now operational.

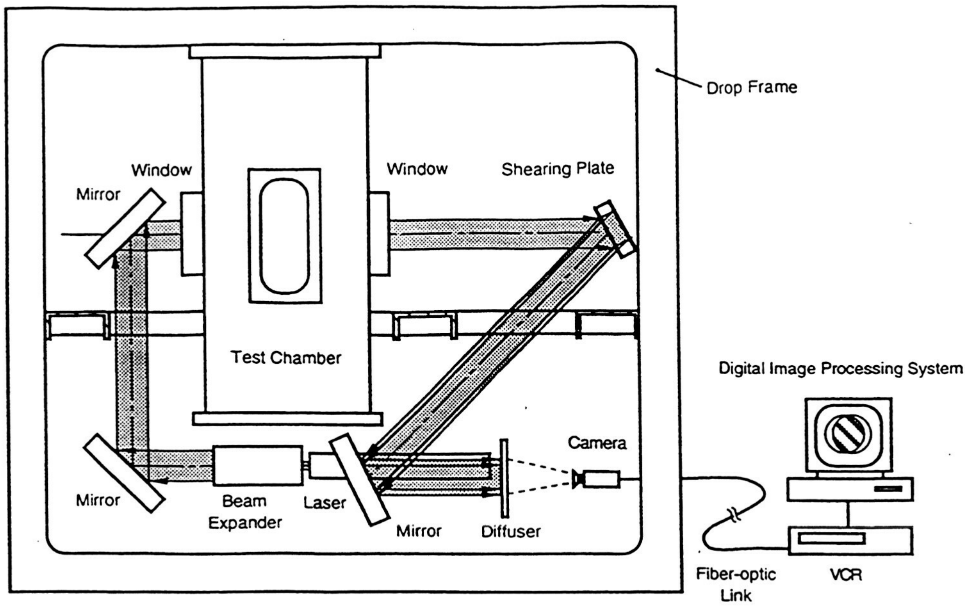
While the focus of this study is on opposed-flow flame spread, corresponding to downward flame spread at one-g, it is useful to compare these results to concurrent-flow flame spread, corresponding to upward flame spread at one-g. It is found (Fig. 3), as expected, that the spread rate is higher for upward flame spread because heat transport is in the same direction as the spread. However, what has not been shown previously is that upward flame spread over thin fuels can be steady, but only for sufficiently narrow samples and/or sufficiently tall samples. This is sensible considering that the early stages of upward flame spread, the spread rate is accelerating due to the fact that the flame length is increasing and thereby the rate of heat transfer to the fuel surface is increasing. When the flame length has grown to the point where transverse losses match the rate of heat generation by the flame, a steady spread rate is observed. Since the transverse losses will be greater for smaller sample widths, the spread rate will be smaller for narrow samples. Morevoer, because these considerations are absent for downward flame spread, the downward spread rate is nearly independent of the sample width.

An analytical study has been initiated in conjunction with Dr. Mike Delichatsios of Factory Mutual Research Corporation in Norwood, MA. The goal of the work is to extend his exact solution of flame spread over a pyrolyzing fuel bed to consider the effects Lewis number, finite-rate chemistry, and gaseous fuel addition on flame spread rate. A preliminary theory of Lewis number effects on flame spread over thin fuel beds, including finite-rate chemistry, has been obtained and compared with prior one-g data from Zhang et al (1992). The results (Fig. 4) are in reasonable agreement except for SF_6-diluted mixtures, which have the lowest oxygen Lewis number ($\approx$ 0.30); current theoretical efforts are aimed at trying to understand the unusual behavior of SF_6.

Publications/Presentations:

Delichatsios, M. A., Ronney, P. D., "Horizontal and Lateral Flame Spread on Solids: Closure and Diffusional Lewis Number Effects," Fall Technical Meeting, Combustion Institute, Eastern States Section, Dec. 5-7, 1994, Clearwater Beach, FL.

Liu, J. B., Ronney, P. D., "Robust Interferometer System for Drop Tower Experiments," SPIE International Symposium on Optical Science, Engineering, and Instrumentation, July 9-14, 1995, San Diego, CA (to be presented).



Side View

Figure 1. Schematic diagram of laser shearing interferometer system for 2.2 second drop tower.

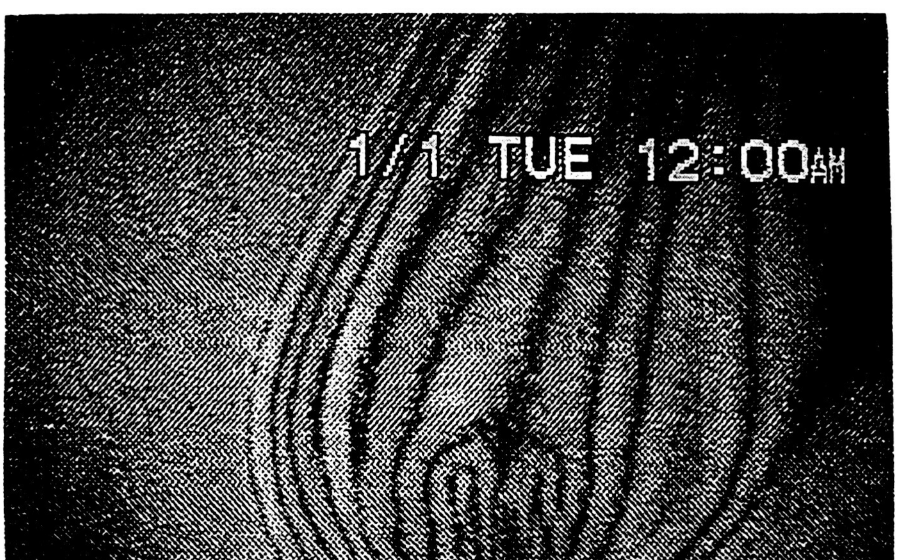


Figure 2. Digitized image of the plume above a burning paper match obtained from the shearing interferometer system.

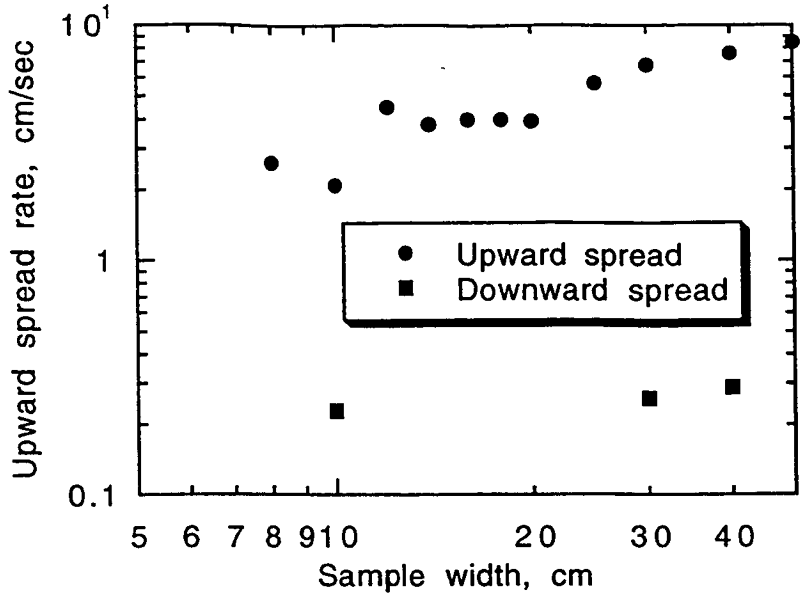


Figure 3. Observed spread rates for upward and downward spread over a thin solid fuel as a function of sample width

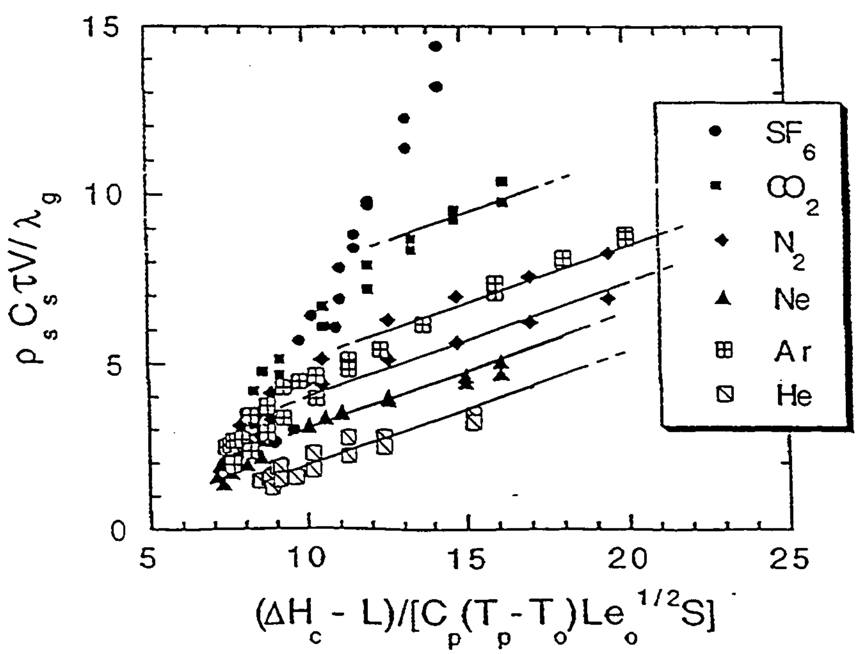


Figure 4. Comparison of model of spread rate over thin solid fuels with Lewis number effects to experimental results.